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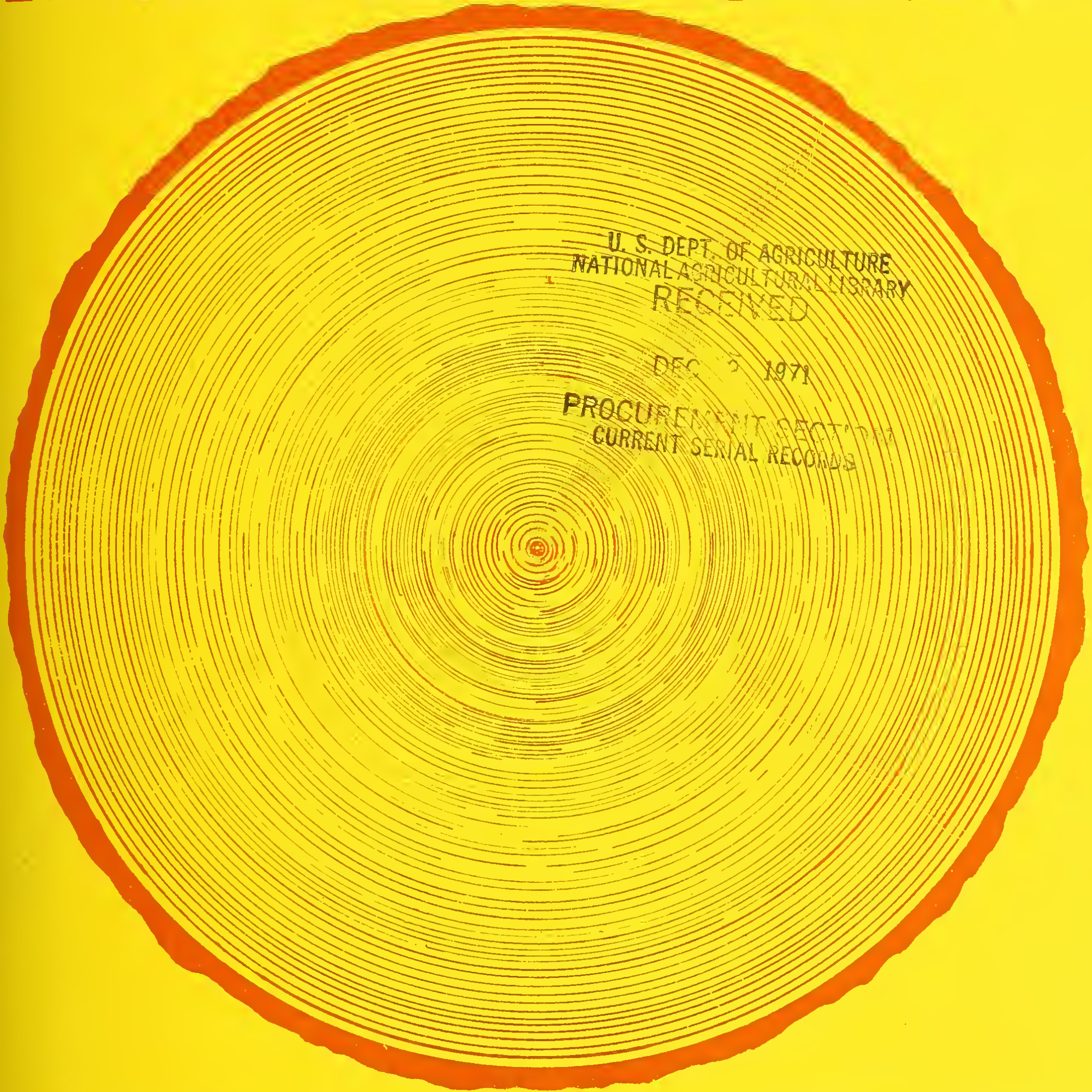
INITIAL THINNING EFFECTS



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CURRENT SERIAL RECORDS

in 70- to 150-year-old douglas-fir—western oregon and washington

[Pseudotsuga menziesii]

Richard L. Williamson
and Frank E. Price

acific Northwest Forest and Range Experiment Station
orest Service
Portland, Oregon
U.S. Department of Agriculture

Richard L. Williamson is mensurationist at Forest Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Olympia, Wash.

Frank E. Price is forester with Management and Program Plans, Division of Timber Management, U.S. Forest Service, Washington, D.C.

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ABSTRACT

Vigorous, mature (post-rotation age) Douglas-fir stands will probably exist for another 50 years or more on some properties in western Oregon and Washington. Intermediate harvests in the form of thinnings were analyzed on nine study areas ranging from 70 to 150 years old when thinned.

Recoverable cubic-volume growth, averaging 81 percent of normal gross growth, was recorded for up to 38 years with single thinnings and for 18 years with two thinnings. This percentage increases with stand age, but rate of response to thinning decreases with increasing stand age.

A dramatic 61-percent reduction in loss caused by bark beetles and substantial reductions in losses from windthrow (30 percent), breakage (33 percent), and suppression (46 percent) were measured.

Reserve basal area may be maintained between 60 and 85 percent of normal. Thinning should follow marking guidelines previously recommended but with more emphasis on crown release since spacing is important in vigorous, mature stands as well as in younger stands.

Keywords: Thinning (trees), forest cutting systems, Douglas-fir, *Pseudotsuga menziesii*, forest improvement cutting.

INTRODUCTION

The purpose of this paper is to present management guides toward maximum recoverable growth in vigorous, mature, essentially even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands. These guides primarily concern stands 70 to 150 years old, though inferences are expected to apply to older stands which are still vigorous. These guides supplement the theory and practice of commercial thinning in younger stands as well documented in USDA Technical Bulletin No. 1230 (Worthington and Staebler 1961).

The present inventory of post-rotation-aged Douglas-fir is so large that immediate harvest cutting is not a practical alternative for all such stands for all owners. Table 1 lists the volume and acreage of Douglas-fir stands in western Oregon and Washington in 1968 by 20- and 30-year age classes. At the average annual rate of cutting (11,530 million board feet) in the years 1960 to 1968, final harvest of all stands now over 100 years of age would take well over 20 years. Since current cutting includes timber types other than Douglas-fir and stands less than 70 years old, probably not more than two-thirds of current cutting comes from post-rotation-aged Douglas-fir. These factors extend the liquidation period for stands currently older than 70 years to well over 30 years. As some owners will be liquidating more slowly than the average, we expect that some vigorous, mature Douglas-fir stands will exist for another 40 to 50 years or more and will urgently need silvicultural treatment during the intervening years. During the next 30- to 50-year period, nearly 28 percent of the Douglas-fir timber types potentially pass through this 70- to 150-year-old range, providing regeneration cuts are not made prior to age 70.

Table 1.—*Inventory of Douglas-fir type, western Oregon and Washington, 1968*[1]

Age class	Area	Volume	
	Thousand acres	*Million cu. ft.*	*Million bd. ft. (Scribner)*
0-20	2,087	945	2,912
20-40	1,734	4,935	11,914
40-70	1,593	7,436	25,952
70-100	852	5,425	27,082
100-120	364	2,925	17,863
120-150	271	2,240	11,142
Total, 70-150	1,487	10,590	53,147
150-180	174	1,721	8,621
180+	2,567	28,222	124,999
Uneven-aged	4,800	24,335	110,644
Total	14,442	78,184	341,129

[1]Data from Pac. Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resour. Bulls.

Most earlier reports concerning thinning of such stands (Steele 1948, 1954; Yerkes 1960) recommend removing only high-risk trees[1] and conclude that thinning cannot be expected to improve growth of residual trees sufficiently for full site utilization. Subsequent analysis (Williamson 1966) of data from some of the same plots reported above, together with more accurate site index estimates and a longer period of observation, convinced us that these earlier recommendations should be reexamined.

[1] Trees likely to die of any cause before the next scheduled cut.

METHODS

Study Areas

Permanent sample plot records for nine study areas were obtained from the Pacific Northwest Forest and Range Experiment Station and the Weyerhaeuser Company. These areas are characterized in table 2, with locations illustrated in figure 1. Some stand, treatment, and growth observations are recorded in table 3.

Table 2.—*Characteristics of existing thinning study areas in young-growth Douglas-fir over 70 years old*

Location (study number)	Legal location reference, Willamette Meridian	Age at establishment	Date of establishment	Remeasurement dates	Site index	Kind of thinning
Salmon Creek (34H)	T21S,R3E	79	1928	1933, 1938, 1944, 1967	148	low, moderate
Fall Creek (W10)	T18+19S,R2E	90	1948	1955, 1967	150	low, light
Indian Creek (W29)	T16S,R10W	77	1943	1947, 1967	170	crown, moderate
Henderson Creek (W14)	T19S,R11W	150	1947	1952	170	crown, moderate
Panther Creek (P22)	T4N,R7-1/2E	97	1939	1946, 1950, 1952, 1957, 1967	150	low, moderate
Boundary Creek (P26)	T4N,R8E	110	1952	1955, 1958, 1963	114 to 150[1]	low, light to heavy
Vail	T15N,R4E	90	1954	1959, 1964, 1967	140	low, heavy
St. Helens (3)	T10N,R3E	100	1946	1951	155	crown, heavy
St. Helens (4)	T10N,R2E	68	1950	1956, 1958, 1963	170	low, heavy

[1] Minor site index variation (± 5 feet) exists around the average presented for other areas. The range presented for Boundary Creek illustrates the extreme variability of one factor influencing growth within this area.

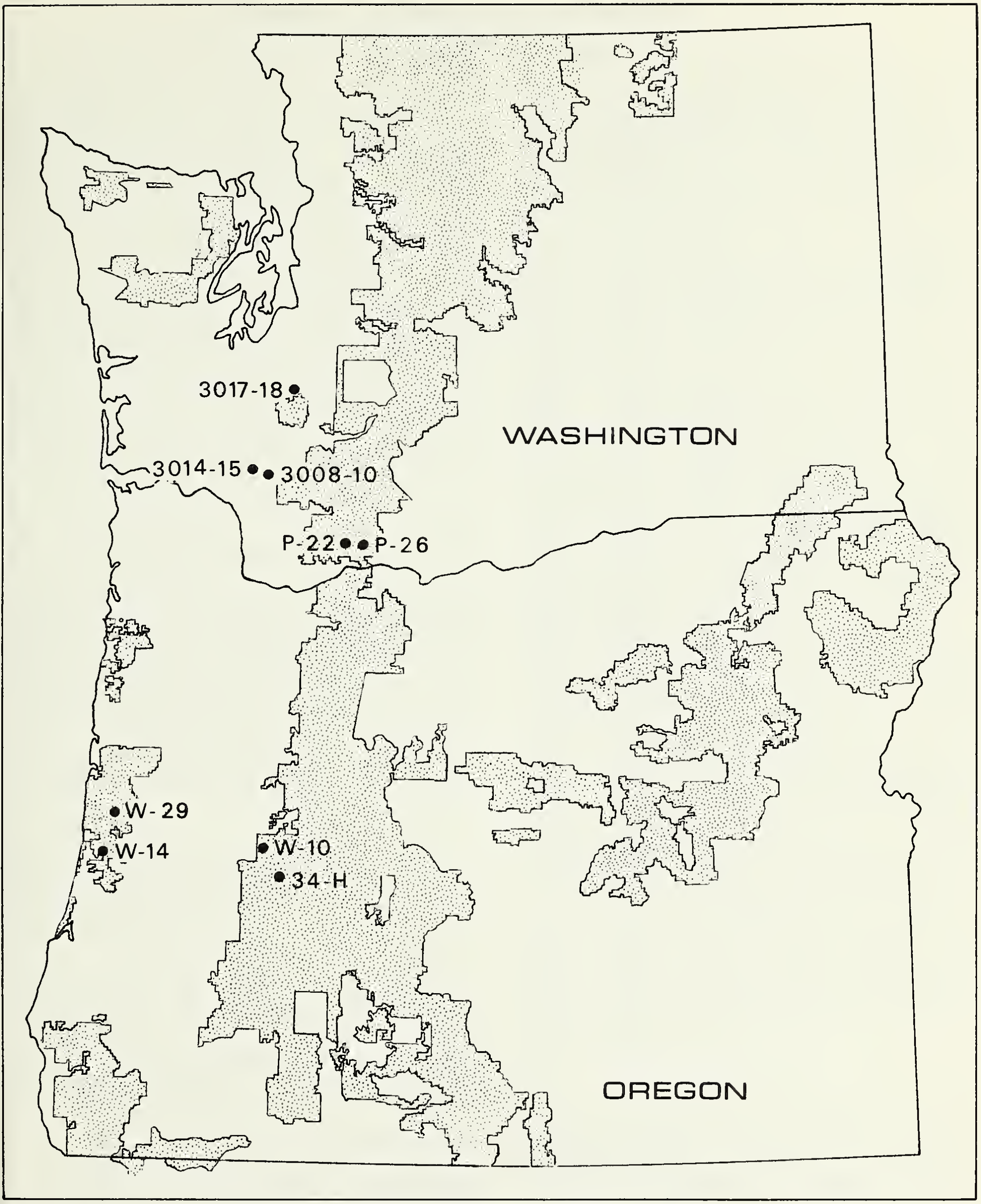

Figure 1.—Study area locations.

Table 3.—*Certain stand, treatment, and growth characteristics*

(Measurements are per acre)

Area (study number)	Plot	Initial basal area	Initial basal area percent normal	Percent cut	Kind of cut d/D[1]	Residual basal area	Overall periodic annual growth: Net		Gross	
							Basal area	Volume	Basal area	Volume
		Sq. ft.				*Sq. ft.*	*Sq. ft.*	*Cu. ft.*	*Sq. ft.*	*Cu. ft.*
Fall Creek (W10)	1	259	92	22	0.83	201	1.8	114	2.7	155
	2	251	88	0	—	251	1.6	119	2.8	169
Henderson Creek (W14)	1	411	119	27	.92	301	2.0	139	2.3	148
	2	398	115	12	1.05	350	2.4	159	2.8	173
	3	337	97	16	.90	282	.1	41	2.1	137
	4	365	106	0	—	361	.8	90	2.9	193
Indian Creek (W29)	26	331	123	28	1.08	238	-.2	10	2.8	152
	27	317	118	22	1.10	247	.1	29	2.6	153
	28	334	124	25	1.01	252	.8	50	2.8	143
	29	356	132	0	—	356	-.9	45	3.0	236
	30	297	110	0	—	297	-3.7	-155	2.0	127
Salmon Creek (34H)	4	200	76	39	.83	122	1.6	98	1.9	112
	5	202	77	0	—	202	.4	64	1.8	122
St. Helens (3)	3008	322	109	55	1.04	172	-3.3	-128	1.3	78
	3009	296	101	38	1.00	196	-1.7	-62	1.6	93
	3010	284	94	0	—	284	2.7	306	3.0	318
St. Helens (4)	3011	295	115	24[2]	.69	236	0	41	3.5	216
	3013	287	112	30[2]	.84	229	3.0	170	3.9	211
	3014	314	123	51[2]	.80	249	3.7	200	3.7	200
	3015	299	117	28[2]	.62	255	3.0	215	3.1	220
	1007	322	126	0	—	322	.6	112	3.6	243
Vail	1098	259	95	0	—	259	2.9	153	3.2	163
	1099	262	96	0	—	262	2.4	134	3.0	155
	3017	270	99	24	.74	204	1.6	47	2.3	76
	3018	254	93	30	.76	178	2.0	99	2.1	103
Boundary Creek (P26)	1	306	101	6	—	287	2.9	138	3.0	146
	2	224	83	36	.89	144	1.3	66	1.3	66
	3	293	97	24	.89	222	1.8	111	2.0	116
	4	264	87	18	.88	216	2.7	126	3.0	134
	5	210	71	22	.80	163	1.5	83	1.6	87
	6	258	87	7	—	239	1.9	113	2.3	133
	7	180	61	2	—	177	.8	57	2.1	111
	8	289	101	22	.90	224	1.0	57	1.6	90
	9	240	92	36	.95	155	.6	34	1.7	70
Panther Creek (P22)	91	306	109	32[2]	.95	237	1.0	57	([3])	([3])
	92	247	86	36[2]	.85	223	.9	54	([3])	([3])
	93	278	96	27[2]	.96	241	1.7	98	([3])	([3])
	94	248	87	27[2]	.93	223	1.2	77	([3])	([3])
	95	254	88	31[2]	.92	237	.6	48	([3])	([3])
	96	250	86	28[2]	.83	232	1.0	73	([3])	([3])
	97	262	91	36[2]	.88	234	1.5	84	([3])	([3])

[1] Ratio of quadratic mean diameter of cut trees to that of all trees before cutting.

[2] Sum of cuts 1 and 2 as percent of basal area before cut 1.

[3] Loss of individual tree identification resulted in estimate of net growth only for overall period.

Most of these studies were early attempts to evaluate commercial thinning. Salable volume was obtained primarily from the larger diameter classes, though plot records and the appearance of the stands today indicate a conscious effort was generally made to leave the best dominants and codominants as crop trees and to remove as many poor intermediate and suppressed trees as possible.

Most of the studies had been abandoned for from 9 to 20 years, perhaps because of a lack of dynamic response to thinning in these older stands and the potential for more rewarding research efforts in more responsive younger stands. Nevertheless, the foresight exhibited by the people responsible for establishing these studies and imposing treatments is remarkable, since the prevailing opinion was that "thinning" in these older stands should be confined to removal of high-risk trees.

Plot Examinations

Diameter (b.h.) on all trees and total height of at least 20 trees per plot were remeasured for all nine areas. Most plots also were examined subjectively for (1) plant (species and vigor) and soil (depth and stoniness) indicators of possible gross errors in site index estimates, (2) external causes of mortality, and (3) other factors that might obscure treatment effects.

Stand Compilation and Summary

Data for each plot were compiled and summarized by the same methods as follows:

1. Scribner and International 1/8-inch board-foot volumes for trees 11.0-inch d.b.h. and larger, to 8-inch and 5-inch tops, respectively.
2. Cubic-foot volumes for trees 5.0-inch d.b.h. and larger, to 4-inch top.
3. Basal area for all trees over 1.5-inch d.b.h.
4. Gross and net growth and mortality, by cause.

Analysis

Most of the studies examined here were established with unreplicated treatments and presented a maze of stand conditions, treatments, apparent site qualities, and growth responses that made reliable empirical evaluation of growth-treatment relationships extremely difficult.

Stepwise multiple regression analysis was chosen as the most acceptable means of developing approximate functions illustrating these growth-treatment relationships. Bias was recognized as probable in some or all tests of significance and in values of regression coefficients, because the data deviated widely from the theoretical assumptions underlying multiple regression analysis. However, the regression trends discussed below fit the observed data very well (overall period correlation coefficient = .97). Because these study areas typify well-stocked stands throughout the Douglas-fir type, we think the trends are generally applicable.

No exact interpretations regarding volume growth will be attempted here since gross periodic annual *basal area* growth is much more precisely estimated than is volume growth. Basal area was the treatment response analyzed by stepwise regression. There is evidence[2] from the Voight Creek Experimental Forest[3] that, in moderately to heavily thinned 38- to 45-year-old stands, absolute form factor for individual trees increased only 0.004 in 9 years, and degree of release did not significantly affect this increase. In addition, height growth in these older stands is small. The trends regarding basal area growth, discussed below, probably apply equally as well to volume growth.

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[2] Data on file at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Olympia, Wash.

[3] The Forest is maintained in cooperation with St. Regis Paper Company.

RESULTS AND DISCUSSION

In addition to the usual beneficial results of thinning (less capital investment, transfer of growth to fewer and better trees, a more vigorous stand with less risk of mortality), two results were readily apparent and deserve initial emphasis. One is that average mortality from bark beetle (in most cases, probably due to Douglas-fir bark beetle) (*Dendroctonus pseudotsugae,* Hopkins) in these thinned plots during the total observation periods was only about 40 percent of that on the unthinned plots.

The second is that stand age and estimated site index are the primary factors influencing long-term growth in these thinned stands, and that other possible factors such as intensity of cut apparently exerted very little additional influence.

First period growth (5 to 7 years after thinning) for these plots can be expressed by the following equation:

$$(1)\quad y = -0.856 + 0.02389(rba\%) + 5346\left(\frac{1}{age}\right)^2 + 0.0003669(site)^{3/2}. \quad (r = .92)$$

Overall period growth (5 to 38 years after thinning) can be expressed as follows:

$$(2)\quad y = -17.372 + 1.948(d/D) + 0.1776(p) - 0.0406(June) + 7907\left(\frac{1}{age}\right)^2 + 0.0015259(site)^{3/2}. \quad (r = .97)$$

In the above equations:

y = Gross periodic annual basal area growth.

$rba\%$ = Residual basal area as a percent of normal basal area.

d/D = Ratio of quadratic mean diameter of cut trees to that of all trees before cutting.

p = Total growing season (May-August) precipitation expressed as percent of normal for the measurement period.

June = Periodic average precipitation for month of June, expressed as percent of normal June precipitation.

Readers should regard these relationships as tentative and use the above correlation coefficients to visualize only how well these equations describe these data.

Factors Influencing Gross Basal Area Growth

RESIDUAL BASAL AREA—PERCENT OF NORMAL—AND INTENSITY OF CUT

Because these stands were well stocked initially and represented approximately normal basal area conditions, "residual basal area" expressed as a percent of normal and "intensity of cut" (percent cut) provided similar, but complementary, expressions of treatment. Figure 2 illustrates observed growth trends relative to intensity of cut, but values on the ordinate scale also can be regarded as approximate percentages of normal basal area stocking because of the above similarity. Recoverable basal area growth (fig. 2) is equal to "net growth plus 80 percent of observed mortality." Different starting elevations for sloping lines indicate different intensities of initial thinning. Degree of slope represents relative growth rate.

Except for plots 3008 and 3009 which had heavy mortality, thinning intensity or residual basal area had little, if any, influence on growth relative to initial basal area (fig. 2). There is some variation in relative growth rate after thinning, but this is largely between study areas and probably reflects differences in stand age at time of treatment. In the 70- to 150-year-age range of these study areas, older stands evidently grow relatively more slowly. To further substantiate this age effect,

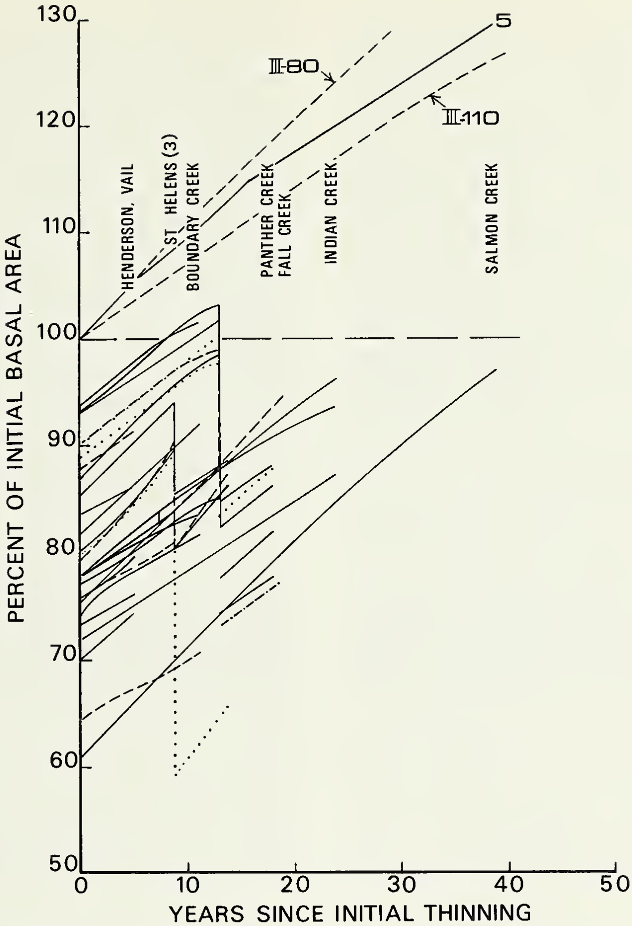

Figure 2.—Time and cutting intensity effects on recoverable basal area growth relative to basal area before cutting. All thinned plots and Salmon Creek plot 5 (unthinned).

two curves for site quality III gross yields (Staebler 1955) are shown by dashed lines—one for stands starting at age 80 and one for stands starting at age 110. The gross yield table values also indicate that site variations should have little influence on the slope of these curves. Values for Salmon Creek plot 5 (unthinned) are included because its long-term record provides a reliable basis for comparing thinned and unthinned stands. Results for this plot are representative of the other unthinned plots which remained well stocked. The curve for this plot represents total gross growth (net plus 100 percent of observed mortality). Growth of unthinned plot 5 declined relative to normal gross growth, whereas *estimated recoverable growth* of adjacent thinned plot 4 almost exactly paralleled it.

An apparent lack of a pronounced growth depression in the first 5 to 7 years after thinning is particularly noticeable. No doubt, some depression occurs in this period, but lack of annual measurements precludes knowledge of its timing and extent. This lack of pronounced depression is so generally contradicted by results from other experimental areas, though generally in younger stands,

that it requires further study. The contradiction may be, in part, due to methodology. In the development of figure 2, thinned plot growth was *not* compared with growth of associated control plots, as is usually done, because before treatment several thinned plots differed appreciably in stand and site characteristics from their respective control plots. Nor was growth compared with normal values. Rather, the stand on each of these initially well-stocked plots was considered as having integrated the influence of all factors affecting productivity on the plot up to the time of cutting. Thus, each initial stand provided its own index to future productivity.

STAND AGE, MIDPERIOD

Gross basal growth during both initial and overall periods was closely dependent on stand age (fig. 3). For a given site index, growth steadily declined with age, though at a decreasing rate. Normal growth trends—indicated by dashed lines—are similar to those measured in this study.

SITE INDEX

Site index obviously is an important predictor of productivity (fig. 3). The site index trends in figure 3, derived from equation 2, however, appear too low for site indices below 140. Only three plots have estimated site index below this value and this paucity of data probably allowed curved distortion. Growth for these three plots corresponded more closely to normal gross yield trends (Staebler 1955) represented by dashed lines in figure 3.

KIND OF THINNING (*d/D*)

Kind of cut (fig. 4, equation 2) appeared to be more important in the overall periods (5 to 38 years) than for the first periods (5 to 7 years), when it usually would be expected to exert its strongest influence. This suggests that the release and growth stimulus provided by spacing upper crown classes are more lasting than those resulting from removing only suppressed and intermediate trees.

(GROWTH $(y) = -3.668 + 1.94791\,(d/D) + 7907\,(1/age)^2 + 0.0015259\,(site)^{3/2}, r^2 = .94$)

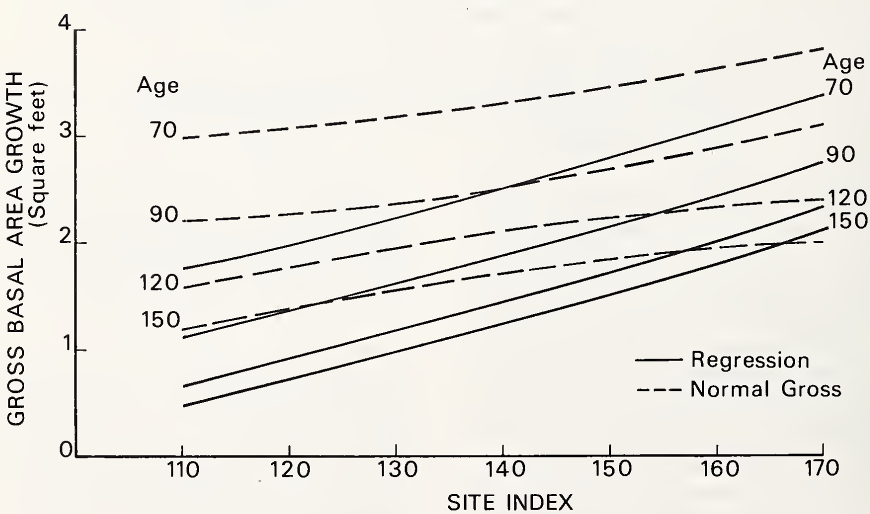

Figure 3.—Gross periodic annual basal area growth expressed as a function of age, site index, and *d/D* where *d/D* = 1.05.

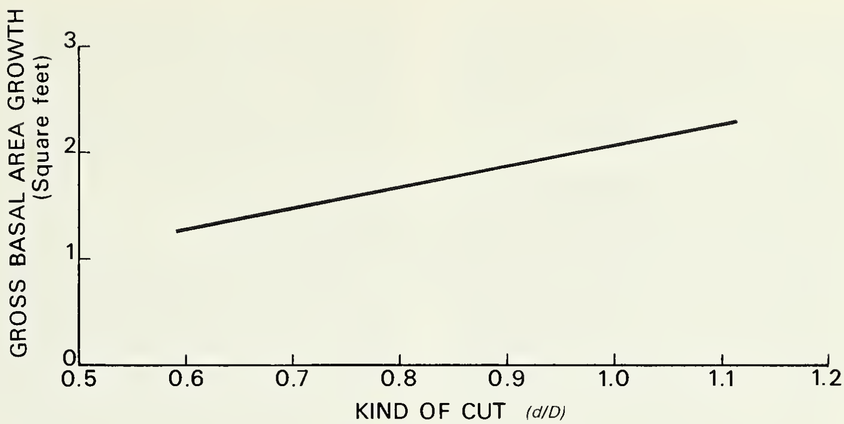

Figure 4.—Effect of kind of cut (*d/D*) on gross total periodic annual basal area growth, for age 90 and site index 150.

Low thinning appeared primarily to benefit other lower crown-class trees for a given amount of basal area removed. Crown thinning appeared to benefit primarily larger trees. This viewpoint is supported by analysis of basal-area growth of trees sampling the entire range of initial diameters in two stands similar regarding age, site, and initial density, one thinned from below (St. Helens 3011, 3014) and one from above (Indian Creek) (fig. 5). In each case, difference in growth is shown by comparison of thinned and unthinned stands. Study areas are not compared directly because of different period lengths. At Indian Creek, where the stand was thinned from above, basal-area growth of larger trees benefited substantially more from release than did that of smaller ones. At St. Helens plots 3011 and 3014, where trees were thinned from below, smaller trees benefited from release more than did larger trees. With respect to basal-area-growth *percent*, all size

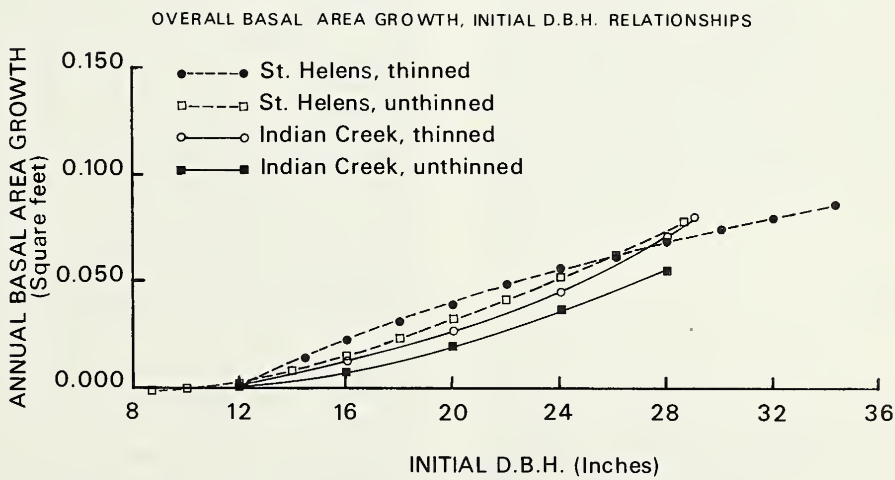

Figure 5.—Periodic basal area growth-initial d.b.h. relationships, Indian Creek and St. Helens 3011, 3014.

classes performed about the same at St. Helens (1.58 percent vs. 1.68 percent for small and large trees); the larger size classes performed considerably better at Indian Creek (1.63 percent vs. 0.95 percent).

TREE SPACING BEFORE THINNING

Response to thinning apparently had no relationship to prethinning density. This is remarkable, considering the wide range in the sample data. Density was expressed as growing space per tree relative to tree height before thinning and is one of numerous possible indices of competition. The ratio—43,560 ÷ number of trees x height—varied between 1.12 and 3.06, and number of trees relative to normal values varied between 55 and 159 percent.

REPEATED THINNING

As only two areas were thinned twice, the data are insufficient to make definite inferences. It seems fairly evident, from the trends of basal area for Panther Creek and St. Helens (fig. 2), that growth following the second thinning approximated that following initial thinning when levels of growing stock were maintained above about 60 percent of normal.

WESTERN HEMLOCK GROWING STOCK

This species generally contributed little or nothing to the growing stock of the studied stands. Appreciable amounts occurred at two study areas (up to 27 percent by basal area), but the occurrence did not appear to have influenced stand response relative to the other areas having little or no hemlock growing stock.

Mortality

GENERAL

Thinning these vigorous, mature stands reduced mortality due to all natural causes (fig. 6). It is likely that repeated thinning would have further reduced thinned plot mortality.

We attempted to relate amounts of different kinds of mortality to stand, environmental, and time variables. Except for windthrow, correlations with these independent variables were too weak to be significant. This is not surprising, considering the sporadic nature of nonsuppression mortality.

WINDTHROW

Concern about windthrow should not delay or forestall thinning, even in high-hazard areas. In these study areas, losses were generally lower in thinned than in unthinned stands. In high-hazard areas, windthrow was most serious immediately after cutting and decreased with time. Observed mortality is expressed by the following equation derived from data for all study areas:

$$y = 0.6282 + 8.01\left(\frac{1}{x}\right)^2. \quad (r = .85)$$

where:

y = windthrow, basal area per acre per year

x = (time since thinning) ÷ 2.

Except for two of the study areas (Henderson Creek, St. Helens 3008-9), plot data indicate that average windthrow mortality was practically constant with time—about 0.3 square foot of basal area per acre per year. These two areas illustrate the adverse results to be expected if sound principles of cutting in relation to windthrow (Gratkowski 1956; Ruth and Yoder 1953) are ignored. Topographic and/or soil characteristics, plus the existence of adjacent clearcuts and intermingled road clearings, evidently made these two partial cut residual stands extremely subject to windthrow. The St. Helens plots 3008-9, being situated on a moist flat in the bottom of a major east-west drainage, were responsible for the indication of much heavier windthrow mortality immediately after cutting. At Henderson Creek, the localized funneling effect of adjacent clearcut boundaries and road clearings on strong winds proved disastrous. Windthrow would have been serious even without partial cutting because of topography and exposure. Equally extensive windthrow in the adjacent uncut area supports this belief.

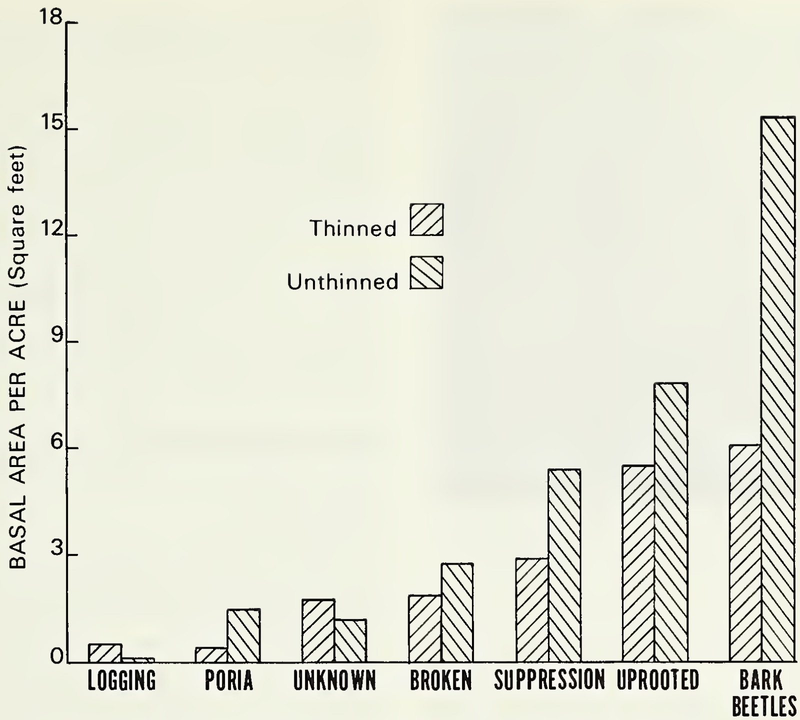

Figure 6.—Comparison of average cumulative mortality for thinned and unthinned areas.

BARK BEETLES

Thinning dramatically inhibited mortality by bark beetles, whether beetle attack occurred concurrently with thinning or followed thinning by varying periods up to 24 years.

Two of the studies were established in stands concurrently experiencing heavy bark beetle attacks. At Panther Creek, all plots were thinned; and at Boundary Creek, insect-infested trees were removed from "unthinned" stands as well as from thinned stands. At both places, bark beetle attacks rapidly subsided.

At a third study area (Indian Creek), bark beetles infested both thinned and unthinned plots soon after thinning and plot establishment. This early commercial thinning left considerable unmerchantable material on the ground. Very high initial basal area (122 percent of normal) probably decreased individual tree vigor. These circumstances apparently favored the bark beetle attack in the thinned stand; and over a 24-year period, the live stand basal area increased only 6 percent. However, mortality from bark beetles was only 42 percent of that in the unthinned plots which actually experienced a 17-percent *decrease* in live stand volume over the same 24-year period. It is likely that repeated thinning with closer utilization would have substantially lowered losses on the thinned plots.

There was no indication that bark beetles were attacking a fourth study area with mortality from bark beetles (Salmon Creek) when the study was established in 1928. Sporadic mortality occurred through the years, but these insects appear to have heavily attacked the unthinned plot during the 1952 epidemic. Most of the snags in this plot (fig. 7) appear to have been dominant and codominant trees,

Figure 7.—Mortality from bark beetles on unthinned Salmon Creek plot 5.

and there is little evidence of past wind damage in the stand. The adjacent thinned stand, heavily thinned from below, suffered little mortality of any kind.

One of the St. Helens plots (3011) illustrates, as did the Indian Creek plots, that thinned plots are not invulnerable to bark beetle attacks. A moderate amount of mortality from bark beetles occurred in this plot in conjunction with a larger amount of windfall mortality. These results confirm reports that abundant windfall (Rudinsky 1966) can provide conditions under which even healthy vigorous trees can succumb to bark beetle attack.

The heavy snow damage to stands in the winter of 1966 and the record drought in the summer of 1967 preceded observations of extensive mortality from bark beetles on the southern end of the Gifford Pinchot National Forest in the spring of 1968. The Boundary Creek study lies in this vicinity, and a 1968 fall examination revealed little mortality or attack on these plots, though considerable mortality occurred on adjacent unthinned areas. Plot mortality was concentrated on one lightly thinned plot where several trees apparently were overwhelmed by mass attack from a large beetle focus just outside the plot.

It is interesting to speculate on the possible benefits that could result from reducing mortality due to bark beetles in vigorous, mature stands throughout the Douglas-fir type to the extent that thinning has reduced it on these study plots (fig. 6). This subject surely merits further coordinated evaluation by silviculturists and entomologists. Some logical reasons for this reduction are presented by Rudinsky (1966) and Vité (1961).

Recoverable Basal-Area Growth

Few of these study areas were rethinned; thus mortality exceeded what one would expect under planned thinning regimes. We assumed that recoverable yield would equal the observed net growth plus 80 percent of the observed mortality. Though arbitrary, this 20-percent reduction in mortality recovery is our best estimate of probable losses to decay and breakage under scheduled thinning regimes.

Recoverable growth averaged 83 percent of normal gross periodic basal-area growth (Staebler 1955) between ages 70 to 110 and increased to about 110 percent at age 150. This relationship does not appear to be affected by estimated site index.

In the absence of planned thinning regimes, salvage operations alone are likely to be sporadic, marginally economic, and, to a large degree, governed by chance. Therefore, no attempt was made to estimate the relative advantages of salvage operations alone.

Cubic Volume Growth Relationships

The foregoing discussion of response to thinnings was related to basal-area growth, but forest managers are more directly concerned with volume growth response. Cubic-

foot volume computations indicate that estimated recoverable cubic-foot growth averaged about 77 percent of normal gross growth (Staebler 1955) between ages 70 to 110 and increased to about 118 percent at age 150. More data are needed before a reliable trend of gross growth percent with age can be determined.

Management Guides

The reader is urged to review the cutting recommendations on pages 49-61 of USDA Technical Bulletin 1230 (Worthington and Staebler 1961), with respect to frequency, intensity, and type and size of trees. Our study indicates that these recommendations generally apply equally well to vigorous, mature stands in the 70- to 150-year-age range. Modifications of certain of these recommendations are discussed below.

PRIORITY OF CUT TREES

Apparently, thinning must improve spacing in the upper crown classes in order to appreciably increase growth of larger trees. Emphasis should not be placed only on removing primarily suppressed and intermediate trees.

Initial thinning in older stands should remove codominant and dominant trees whose removal will relieve clumpy conditions and provide release to better codominants and dominants. Removal of high-risk, lower crown-class trees is equally important. These findings suggest a slight revision (fig. 8) of figure 30 in USDA Technical Bulletin 1230 (Worthington and Staebler 1961). We suggest that spacing is important in vigorous, mature stands as well as in younger ones.

INTENSITY AND FREQUENCY OF THINNING

Foresters have considerable flexibility in varying the kind and intensity of thinning in older stands to suit market conditions and owners' general objectives of cutting.

One apparently can vary levels of growing stock as was done on these study areas (where 60 to 93 percent of normal were retained) and be assured that residual stands will retain near-maximum utilization of their sites. Stand and treatment conditions varied widely on these plots; yet in the analysis of overall period growth, no variable reflecting intensity of thinning appeared to influence growth.

The above treatments should probably be considered in conjunction with maximum

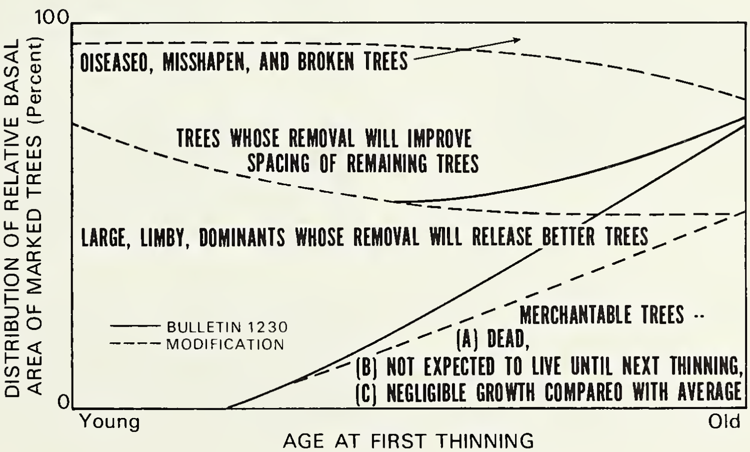

Figure 8.—Distribution of marked trees by relative basal area for initial thinnings of stands ranging from young to old. Modification of Figure 30, USDA Technical Bulletin 1230 (Worthington and Staebler 1961).

thinning intervals corresponding to about 10 feet of height growth. Although this is an untested standard in the Pacific Northwest, it is used in the British forest management tables (Bradley, Christie, and Johnston 1966) for young Douglas-fir and indicates, for instance, a reasonable interval of 15 years for a 100-year-old site index 140 stand. Shorter intervals with lighter cuts can be expected to improve the proportion of mortality that is converted to utilized growth and to provide leeway for such variables as local economic conditions and landowners' objectives.

These recommendations for vigorous, mature stands essentially agree with those of Harmon (1969). His recommendations apply to stands managed from an early age (even when precommercially thinned) so that potential crop trees would never be subjected to severe competition. His recommendation that intermediate cuts remove lower crown-class trees does not conflict with our recommendation to favor crown thinning to space upper crown-class trees, because of the difference in stand histories. Under the regimes he projects, it is likely there will exist no lower crown-class trees such as those found in previously unthinned, vigorous, mature stands. His regimes will remove less desirable codominants to give better trees room to grow; this is, essentially, what we are recommending.

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